8

SAFETY REVIEW OF OPERATING NUCLEAR FACILITIES

Early Days

After the very first two reactors of DAE, Apsara and CIRUS went into operation Bhabha set up a formal reactor safety committee in 1962 with A.S. Rao as the Chairman and V. Surya Rao, V.N. Meckoni and A.K. Ganguly as members. When DAE-SRC was constituted in February 1972, it took over the responsibility for safety review of all research reactors. In December 1975 when DAE reconstituted the DAE- SRC, its scope was enlarged to cover all facilities, not only power reactors or research reactors but all other facilities as well in DAE family. That was the time when DAE was embarking on several major projects covering all components of the fuel cycle at different sites. DAE-SRC was to report to the Chairman AEC. Its first Chairman was A.K. Ganguly, the then Director, Health and Safety Group, BARC who had made pioneering contributions in the area of Health Physics and who enjoyed a great respect and admiration from one and all in the department. He had a very strong team too with members like R.K. Garg, S. D. Soman, B.S. Prabhakar, N. Veeraraghavan and P. Abraham who were all outstanding experts in their own areas of specialization. It is the strong foundation laid by these pioneers that has been responsible for the strong organization AERB built to carry out effectively its mandated responsibility of ensuring the safe operations of the DAE plants.

Prior to establishment of SRC, DAE had formed separate unit safety committees for individual reactors like PURNIMA I, PURNIMA II and plants like Plutonium Plant PREFRE, etc. The DAE-SRC was intended as an apex body for such safety committees overseeing the specific facilities. That was the first step in establishing a robust arrangement of multi-tiered safety review mechanism. The SRC's role was to evolve major safety policies and lay down guiding principles, so that the safety standards and approaches followed remain uniform, across the different sectors of Atomic Energy operations in the country.

To begin with the SRC did not have a permanent office or premises. The Committee had its first meeting on January 6, 1976 at the office of its Chairman, Ganguly, at the sixth floor of Central Complex, BARC, Trombay. The initial decisions were on establishing the reporting criteria and the working procedures of the committee. Following the principle of fair representation of the stake holder's position, SRC adopted a policy of inviting representatives of the facility management and suitable peer specialists, whenever discussing matters relating to individual units.

In those initial days the SRC used to meet nearly on a monthly basis mainly to discuss the operational and radiological safety aspects of TAPS-1&2 and RAPS-1. The committee was also dealing with the safety review and clearances associated with the projects that were under construction at that time, RAPS-2, MAPS-1&2, Heavy Water Plant (Kota), FBTR at Kalpakkam.

While the operational domain of SRC was expanding, its secretariat and infrastructure were also growing. By the end of 1976, SRC had its own premises, a few office rooms in the fourth floor (south wing) of Central Complex of BARC. It also had a conference room for the committee, which came to be known as the SARCOP Conference Room subsequently. This office remained with SRC and later on with the Operating Plants Safety Division of AERB, till June 1996, when all the AERB offices were moved to Niyamak Bhavan. By the year 1976, SRC had established a secretariat having a few engineers / scientists and a handful of support staff led by P. Abraham. The secretariat had a decent library of scientific / technical publications concerning nuclear and radiation safety, sourced mainly from IAEA, ICRP and US-NRC.

Feedback of Operating Experience

By 1978, the SRC had established the requirement and format for reporting of unusual occurrences, which came to be known as the Safety Related Unusual Occurrence Reports (SRUOR) and presently known as the Significant Event Reports (SER). The purpose of this format was to set uniform criteria with respect to the events to be reported and the details to be included in the SRUORs, from different installations. SRC also wanted the system of event reporting to function as a means for obtaining a feedback from operating experience. SRC felt that there was a need to disseminate the information coming from different plants on the events encountered and the lessons learnt.

With these objectives, a decision was taken to set up a computerised databank in the SRC Secretariat. Even though DAE-SRC had installed a HCL-Honeywell Machine, then a state of the art computer system, it required enormous efforts to create a data base on unusual occurrences and SRC recommendations. There used to be those quarterly compilations on the SRUOR/UOR and the list of pending recommendations, being sent to all units of DAE. This sound tradition is being continued till date with several enhanced features.

This exercise became very handy when in 1984 India became a participant in the IAEA Incident Reporting System (IRS). This added a major boost to the efforts and inputs in the field of Operational Experience Feedback (OEF). We started getting detailed reports on the events that occurred in the overseas nuclear facilities, which provided an insight into the safety of our own facilities. Later India also became a participant in the International Nuclear Event Scale (INES), when IAEA launched it in 1990. The objective of INES was prompt communication of safety significance of nuclear and radiological events to the public.

With the experience of participating in these international programmes and with the data coming in from the events in Indian

NPPs, an in-house system of in-depth analysis of the SRUORs of Indian NPPs was started in the late eighties. It involved analyzing and categorizing the events from the perspectives of failed / affected systems and root causes. OPSD started issuing periodic reports (annual) on the analysis of events which is still continuing. Over the last two decades, with the enormous data gathered and analyzed, the system had provided significant insights which influenced the NPP designs, operational practices and the regulatory approach.

Radiation Exposures at NPPs

In 1977-79 high radiation exposures in the operating NPPs became an issue to be dealt with by SRC with the annual collective dose at TAPS reaching 5000 man-rem. There were also a few cases where annual exposure of individual workers exceeding five rem, the limit for individual exposure recommended by ICRP. At RAPS, there were a large number of persons who received exposures in excess of the investigation levels, though within the annual dose limit and there were delays in completing the investigations. Many of the exposures were due to internal uptake of tritium, which were attributable to non-use of protective equipment. Concerned, SRC took a review of the situation in both TAPS and RAPS.

At TAPS the problems were many; the background levels were high due to poor fuel performance in those days. Tube leaks in secondary steam generators also needed frequent inspections / repairs / maintenance that were man power intensive. When SRC's emphasis was "no annual individual exposure of more than five rem", TAPS's response was with the emphasis on "optimisation" and that a limit on individual exposure would result in increased station dose as it would become necessary for the station to bring in more persons from outside TAPS, who may be comparatively less familiar with the jobs. However, the SRC prevailed on TAPS to agree to have a limit of 4.25 rem on individual exposures and 4000 man-rem for the annual station dose as a first step towards gradual decrease to 1000 man-rem limit.

Despite the emphasis by the SRC and later by AERB and SARCOP and also the efforts by the stations, the collective dose at TAPS, RAPS and MAPS remained high with the exposure exceeding the recommended level of 1000 man-rem. The problems were aplenty. In TAPS, high radiation backgrounds resulted from poor fuel performance, and build-up of activation product Cobalt-60. There were also frequent incidents of tube failures in Secondary Steam Generators and leaks in the SS piping of primary system requiring repairs. In RAPS, the major contributors for the increased doses were poor fuel performance, the cracks in the end shield of RAPS-1, the increasing levels of tritium in PHT resulting in internal exposures and coolant channel ISI / creep adjustment activities. In MAPS also Cobalt-60 activity in PHT system was a major source of high radiation level. The other causes were spillages of heavy water and repair works following failure of moderator inlet manifolds in the calandria of both the reactors.

In 1988, then Chairman AERB, A.K. De constituted a committee under the Chairmanship of T. Subbaratnam, to investigate the possibility of reducing collective doses in the NPPs/installations. This committee, after completing its investigations and reviews, submitted its report in December 1989. The committee made a number of recommendations to achieve reduction in dose consumption at the NPPs. The important recommendations of this committee included stronger commitment from the management, coordination between operation, maintenance, design and health physics groups, appointment of ALARA coordinators at every station, optimization of manpower involved in radiation jobs, steps to improve fuel performance, reduction in tritium activity in PHT system in PHWRs and strengthening of training. The recommendations also included a number of plant specific improvements. The committee had also recommended a limit of 1000 man-rem for the twin unit stations, which were in operation at that time, viz., TAPS, RAPS and MAPS. The committee also recommended that the collective dose in new

220 MWe stations should be below 600 man-rem. The stations should work out and implement comprehensive action plans to achieve these targets.

The Board of AERB had discussed the report of this committee in its meeting in March 1990, and decided to take up the issue of reducing the collective doses at NPPs and implementing the recommendations of the committee, at the highest levels in the Department and NPCIL, i.e., with Chairman, AEC and Managing Director of NPCIL. The constant efforts within AERB and commitment from the top management of NPCIL a number of steps were implemented with the objective of bringing down the collective doses. The major ones were (a) steps to improve fuel performance, including stringent quality control during manufacturing, (b) development and implementation of chemical decontamination of systems to bring down radiation fields before major jobs, (c) steps to reduce internal exposures, (d) tools for automation and remotisation of maintenance activities, and (e) implementation of ALARA programmes. With the implementation of these measures over the years, exposures could be brought down to below 1000 man-rem, in the first half of nineties and to further lower levels in the subsequent period, in the older plants. Currently, while collective dose in TAPS and NAPS is below 500 man-rem, for all other twin unit stations it is below 300 man-rem a year.

Impact of Three Mile Island Accident

The accident at the Three Mile Island (TMI) NPP Unit- 2, on March 28, 1979 was one of the most significant events in the history of commercial nuclear power industry as it is often cited as a turning point in the global development of nuclear power. The aftermath of the accident led to sweeping changes in the emergency response planning, operator training, human factors engineering, radiation protection, and many other areas of nuclear power plant operations. It is worth noting that despite the severe damage to the fuel, the containment system performed adequately and no member of the public received exposure in excess of the prescribed limits. But the accident also bared many shortcomings in the emergency response machinery and provided major lessons about the response of the public in an emerging accident scenario.

At this point of time, TAPS-1&2 and RAPS-1 were in operation in India. There were another five 220 MWe PHWR units under various stages of construction. In view of the widespread concern about the safety of nuclear power plants and the public around them DAE decided to undertake a thorough re-apprisal of the safety of the NPPs in the light of the lessons learnt from the TMI event. In June 1979, Secretary, DAE, H.N. Sethna constituted a Taskforce under the Chairmanship of M.R. Rao, the then Head, Reactor Operation Division, BARC, to study in detail, the safety aspects of TAPS and RAPS and come up with early recommendations. The report submitted by the Taskforce was discussed by SRC in an extended meeting, held during October 1979. The review focussed on the reliability and availability of the engineered safety features, human engineering aspects and emergency preparedness in the public domain. The Taskforce made a number of recommendations for the operating plants, RAPS-1 and TAPS as well as for the new plants under construction at RAPS-2, MAPP and NAPP. Recommendations were also made for other future plants yet to be built beyond NAPP.

It was recognized then that implementation of these recommendations could take considerable time as they involved many preparatory activities like working out detailed designs, engineering, procurement, civil construction, etc., which would require long lead time, and some of which required integration with the existing plant systems. Also some of these recommendations required detailed analytical studies or design reviews towards obtaining better understanding of the phenomena and for developing tools for analysis and validation, etc.

Many of the recommendations of the Taskforce were considered important and it was felt that there should be a strong system for follow-up and enforcement from the part of SRC for systematic and timely implementation of the recommendations. SRC established a computerized database of the recommendations of the taskforce, to assist in monitoring of implementation status and follow-up.

This mechanism was later extended to cover all recommendations arising out of reviews by SRC and later by SARCOP. The staff of OPSD keeps track of these recommendations arising out of safety review. The status is periodically reviewed and updated based on the feedback coming from the plants and the periodic regulatory inspections. The status is periodically brought to the attention of the plants and the corporate organizations. The Operating Plants Safety Division, the unit Safety Committees and SARCOP periodically take stock of the progress and status of implementation. This exercise of stocktaking and review is an ongoing process. From time to time, the Board of AERB is kept informed of the outstanding status of implementation of important recommendations, and the enforcement measures undertaken.

Impact of Chernobyl Accident

Seven years later in 1986, SRC, had initiated another special safety review of Indian NPPs in the wake of the most severe nuclear accident to date, the one at Chernobyl. The review by the Taskforce re-emphasized the necessity of adhering to the already established principles of reactor safety in design and operation and maintaining good safety culture. As recommended by the Taskforce, the organization and procedures for on-site and off-site emergencies were strengthened at all the power stations.

RAPS-1 End Shield failure

Towards the end of 1981, RAPS-1 had to be shutdown due to leakage from its south end shield. After detailed investigations and elaborate repair programme when the unit was restarted in 1985, it sustained yet another leakage. Finally the problem of south end shield stabilized in 1987. But after the leak repairs were completed in May 1987, the utility management opted to restrict the reactor operating power to 50% FP. All these repair works involving significant man-rem expenditure were closely monitored by DAE-SRC.

SRC: Transition to SARCOP (1983-1993)

In November 1983, when AERB was formed, V. N. Meckoni was the Chairman of SRC. Following him, P.R. Dastidar became Chairman of SRC in April 1984 and his term continued till May 1986. Subsequently M.V. Ramaniah served as Chairman of SRC, till June 1987, till M.S.R. Sarma became Chairman of SRC. All these years since inception in 1975, P. Abraham continued to serve as Member Secretary of SRC. In June 1987, N.K. Jhamb took over as Secretary of SRC.

Life Management of PHWR Coolant Channels

One of the main features in PHWRs is the provision of pressure tubes made of zirconium based alloy which serves as the fuel channel as well as the pressure boundary for the primary reactor coolant. Safety of the reactor system requires reliable performance of the tube throughout its design life as it operates at high levels of temperature, pressure and neutron flux. In 1983, a catastrophic failure of zircaloy-2 pressure tube took place at the Pickering NGS Unit-2, in Canada. This event had raised generic concerns on the integrity of pressure tubes in all the operating PHWRs. The cause was determined to be a complex phenomenon involving formation of brittle hydride blisters on the pressure tube. Cracks originating from these blisters resulted in catastrophic failure of the pressure tube. The channel G-16 had ruptured without a prior detectable leakage, thus not satisfying the “leak before break” criteria, one of the basic design principles depended upon for nuclear systems, to assure safety. The zircaloy-2 pressure tubes, during reactor service undergo degradation due to irradiation embrittlement and hydriding due to pick up of hydrogen in the pressure tube material, following a corrosion reaction between the pressure tube material and the reactor coolant.

The DAE-SRC reviewed the available information on the above failure and recommended for initiating a programme for health assessment and life management of pressure tubes in Indian PHWRs. In parallel, PPED was asked to develop detailed emergency operating procedures for dealing with such failures should they occur.

Pursuant to this, a major program was launched for coolant channel life management which involved enhancement in design as well as in-service inspection, health assessment and rehabilitation technologies. BARC provided strong research and development support in this regard. The efforts included development of technology and equipment for inspection of coolant channels and sampling of pressure tube material, analytical models for health assessment and prediction of residual life, technology and tooling for rehabilitation measures like repositioning of garter springs, creep measurement and adjustment, removal and reinstallation of pressure tubes, post irradiation examination of pressure tubes removed from reactor for evaluation of material properties. The main objective of the programme was prevention of blisters of unacceptable size in the pressure tubes. This could be realized thanks to the sustained efforts put in by the NPCIL and BARC under the close surveillance by SRC and later SARCOP. The success of the whole approach followed is evident from the fact that, the last of the reactors with zircaloy-2 pressure tubes, NAPS-2 and KAPS-1, were operated to almost 12 Effective Full Power Years, without encountering any pressure tube failures.

The issue of coolant channel safety, in particular for clearances for operation of RAPS-2 and MAPS-1&2, was the one single issue, on which the SARCOP had spent maximum time for reviews, during the nineties. The situation had changed only after an Expert Group on Coolant Channels was formed in 1998, bringing in all the personnel involved in various aspects of coolant channel life management. This Expert Group reviewed in detail all the safety issues related to relevant coolant channels, in both operating PHWRs and the ones under design / construction. Presently with all the zircaloy-2 pressure tubes phased out of operation, the focus is now on the life management issues of Zirc-Niobium pressure tubes.

Based on the findings of inspections and health assessments, each of the operating reactors went for en-masse replacement of coolant channels (EMCCR), wherein the old irradiated zircaloy-2 pressure tubes were removed from the reactors and replaced with new pressure tubes of better material, Zr-Nb, with four tight fit garter springs. RAPS Unit-2 was the first unit, which went in for the EMCCR, in 1994, after completing 8 Effective Full Power Years (EFPY) of operation. Subsequently, MAPS-2 underwent EMCCR in 2002 after completing 8.5 EFPYs, followed by MAPS-1, in 2003, after completing 10.1 EFPYs. NAPS-1 underwent EMCCR in 2005, after completing about 10 EFPYs. NAPS-2 and KAPS-1, last of the reactors with zircaloy-2 pressure tubes are presently undergoing EMCCR, after completing nearly 11 EFPYs.

A dedicated Review Group was constituted by SARCOP for detailed review of all aspects related to the EMCCR campaign. The regulatory aspects included (a) identification of clearance stages for the activity, (b) review and qualification of various tools, procedures and personnel, (c) inspection, health assessment and qualification of the components that will be retained for further operation, (c) issues related to handling and disposal of the radioactive components removed from the reactor, (d) collective dose budget and performance, (e) aspects related to preservation of other plant systems during the extended outage period, (f) design safety review of the components being replaced.

Formation of SARCOP and OPSD

After the reconstitution of SRC in June 1987 by Secretary DAE, the committee started functioning under the Chairmanship of M.S.R. Sarma. It was during this time, the practice of holding the meetings on Wednesdays, unless in case of any urgent requirements, came into being. A year after its reconstitution of June 1987, the SRC had its last meeting, meeting no. 365, on June 1, 1988. The reorganization of AERB, which came two days later, saw many changes in the organizational and functional arrangement of the safety review committees. The changes involved converting what was the secretariat of the SRC, along with its staff and premises as the Operating Plants Safety Division (OPSD) with M.S.R. Sarma as its Executive Director and constituting a new Safety Review Committee for Operating Plants, famously known as SARCOP, in place of the erstwhile SRC. The Executive Director OPSD was to be the full time ex-officio Chairman of SARCOP, who would be reporting to Chairman AERB. The OPSD was made responsible for implementing the decisions of SARCOP, through issuance of clearances, periodic audits and inspections and enforcement actions with respect to the operating plants. All the unit safety committees, which were working under the SRC, were also brought under this umbrella arrangement. Though this was a major organizational change, the functioning of the safety review and enforcement mechanism for operating facilities continued in a seamless manner. M.S.R. Sarma served as Chairman of SARCOP and Executive Director, OPSD, until his superannuation in August 1991.

A number of issues and incidents pertaining to the NPPs, research rectors Dhruva and FBTR, Fuel Cycle and Waste Management Facilities were deliberated in SARCOP. During this period, SARCOP made a number of visits to the plant sites and held discussions with the plant personnel. There were many important issues taken up during this period, such as the fuel handling event at FBTR and the rehabilitation activities, incidents of failures of shut off rods in Dhruva reactor, fuel failures in Dhruva, inspection and health assessment of feed water nozzle of TAPS reactors, incidents of leakage of hydrogen sulphide gas at heavy water plants at Manuguru and Kota, review and revision of emergency preparedness plans, the safety criteria for PFBR, high collective dose consumption at the NPPs, incidents of fire in the boiler rooms in RAPS and MAPS due to oil soaked insulation and poor house keeping, flooding of low lying areas in BARC Complex due to heavy rains in June 1991, etc.

Failure of Calandria Inlet Manifolds in MAPS Reactors

During 1988-1989, MAPS encountered a heavy water leak inside calandria vault. The leak was from the PHT system, apparently due to leakage from a pressure tube. Extensive investigations revealed failure of the moderator inlet manifolds, a device meant to bear the brunt of high velocity jet of moderator entering the calandria and to distribute the flow evenly. The leakages of calandria tubes and pressure tubes experienced were caused by the impact of the moderator jets and the pieces of the failed manifold. The interim solution to continue the reactor operation involved a major modification in the moderator flow configuration; virtually reversing it inside the calandria; using the old outlet as new inlet, blanking the old inlet and using the dump tank as new outlet. The flow rates and flow velocities were reduced to reduce chances of further failures. To ensure margins on various parameters, the reactor power was derated to 75% FP.

SARCOP and the RAPS-MAPS Safety Committee had reviewed a number of issues associated with the above, viz., changes in the moderator flow and level control logics and its impact on safety, effect of modified flow configuration on the calandria tube rolled joint temperature and health of the rolled joints, temperature distribution inside calandria and the margins available in the modified configuration, permissible reactor power, rehabilitation of the failed manifolds to obviate secondary failures, etc.

Bifurcation of Technical Specifications

Another important initiative came in this period was the bifurcation of technical specifications for operation of TAPS, RAPS and MAPS. The technical specifications documents specify the requirements with respect to aspects such as safety limits, limiting safety system settings (LSSS), limiting conditions for operation (LCO), surveillance requirements and administrative controls, which had varying significance with respect to safety. Moreover, it was also felt that some of the requirements specified in sections other than the safety limits and LSSS, might not be of real importance to safety. There were views that with such clauses present in the technical specifications, strict enforcement of the technical specifications might be difficult as reactor shut downs might become unavoidable for reasons which may not be really important to safety. With this backdrop, SARCOP initiated an in-depth review of technical specifications of the then operating rectors, TAPS, RAPS and MAPS, in 1990. Based on the review and the operating experience available, the technical specifications documents were bifurcated into (a) Technical Specifications, which contained the mandatory provisions which needed to be strictly adhered and the utility would be accountable to the regulator and (b) Station Policies, which comprise of the less important and desirable requirements as well as the good operating practices, which should be enforced by the operating organization itself. The change essentially involved transferring the requirements, which did not have any direct implications on safety or the safety related systems and the sections on administrative controls and details of surveillance requirements, to the station policies. While this exercise of rationalizing the technical specifications did help in improving adherence to the technical specifications, cases of deviation do take place albeit with prior permission of SARCOP, in most cases. There were however certain deviations from the station policies in these stations, the responsibility of follow up of which was with the NPC Headquarters, with periodic reporting to SARCOP.

There were requests in the subsequent years from NPCIL seeking similar bifurcation of technical specifications of NAPS onwards. However the assessments and opinion in OPSD and SARCOP were that such bifurcation had not significantly improved adherence to Technical Specifications and the mechanism in NPCIL for enforcement of station policies was not strong enough and formal. Therefore, the requests for bifurcation of technical specifications of other stations were not acceded to.

Special Review Committees

AERB had set up a number of Committees chaired by senior professionals to review in detail some of the issues concerning the operating NPPs. Important among these were as follows.

Review of unusual incidents at RAPS (1980-84)

Chairman AERB set up a Committee in 1984 chaired by P. Rama Rao, the then Director, Defence Metallurgical Research Laboratory to review the unusual occurrences in Rajasthan Atomic Power Station during 1980-84 for identifying issues related to equipment material and fabrication procedures, etc., that were generic in nature.

The Committee identified the generic issues that needed special consideration like reliability and availability of emergency power supplies, adherence to operating procedures and maintenance practices, need for procurement of equipment of proven quality, layout of equipment and amenability for easy maintenance, etc.

Of the 547 incidents and 115 outages included in the report, 89 incidents and 43 outages were reviewed by the Committee as the major ones. The Committee observed that the station management had put in considerable efforts in bringing the unit to an improved level of operation and maintenance as reflected by the good performance of unit-2 in 1985 and its continued record performance in 1986.

Review of operational safety at TAPS

In July 1985, Chairman AERB set up a Committee chaired by K. Sri Ram, IIT Kanpur, to review the operational safety aspects of Tarapur Atomic Power Station. Based on the review, the committee concluded that the health of plant was satisfactory for continued operation. The committee noted that the Station management was responsible and technically alive and alert in so far as assuring personnel, plant and public safety were concerned.

The recommendation of the committee addressed formalization of quality assurance practices, improvements in the enforcement of industrial safety and enhancing the infrastructure availability for fire safety.

Review of QC and QA at NPPs

Chairman AERB constituted a committee in 1985 chaired by B.S.Magal, IIT, Bombay to review quality control and quality assurance for nuclear power plants. The committee made a number of recommendations after reviewing the then prevailing mechanisms for quality control, quality assurance, inspection practices and their enforcement in the manufacturing of critical components for the nuclear power plants. The committee had also made recommendations regarding qualification training of QA and QC personnel and in-service inspection procedures followed in nuclear power plants and projects on safety systems.

Review of operational safety at RAPS and MAPS

In September 1989, Chairman AERB appointed a Committee chaired by N. Srinivasan, former Chief Executive, HWB to review the operational safety of RAPS and MAPS. The committee exhaustively reviewed the management, organization and administration, training, operation, maintenance, fuel handling, technical support, radiological protection, emergency preparedness, etc. The Committee made many recommendations in each of these areas which were implemented over a period of time and monitored by AERB.

Directives on Dose limits

In 1990, the ICRP came out with its recommendation, ICRP-60, wherein an additional dose constraint of 100 mSv averaged over a period of five years was suggested as against the earlier recommended standalone annual dose limit level of 50 mSv in a year (ICRP-26). Pursuant to this AERB decided to progressively bring down the dose limits applicable for Indian Facilities. In 1991, AERB reduced the annual dose limit to 40 mSv, followed by 35 mSv in 1992 and 30 mSv in 1993. The Safety Directive issued by Chairman AERB in March, 1994 also had the limit of 100 mSv averaged over a five year period in line with ICRP recommendations.

SARCOP: The Consolidation (1991-97)

Following M.S.R. Sarma, S. Vasant Kumar served as Chairman of SARCOP and Executive Director, OPSD between September 1991 and October 1998. In 1997, he went on to become the first Vice-Chairman of AERB. There were many important events and developments during this period. Two new NPPs graduated to the fold of Operating Plants. In 1992, the NDSC completed the reviews associated with the design, construction and commissioning of NAPS reactors, first of the standardized 220 MWe PHWRs. AERB had then handed over the responsibility of safety review and surveillance to OPSD and SARCOP. The handing over involved essentially a meeting between SARCOP and NDSC, where the SARCOP and OPSD officers were briefed on the reviews done and the outstanding issues requiring follow up and a comprehensive formal document, bringing out the detailed historical and technical aspects of issues for follow up. Five years later, the safety review responsibilities of KAPS were also given to OPSD and SARCOP after satisfactory review of design, construction and commissioning stages by the KDSC (KAPP Design Safety Committee) and ACPSR (Advisory Committee on Project Safety Review), in 1997.

Technical Specifications for Other Nuclear Facilities

Previously only the NPPs, research reactors, heavy water plants and fuel reprocessing plants were having technical specifications. The basis of regulatory actions for facilities such as Nuclear Fuel Complex (NFC), Indian Rare Earths (IRE) at UCIL were essentially the Atomic Energy (Factories) Rules and the broad guidelines or principles of industrial hygiene. In 1993, SARCOP undertook the exercise of preparation of Technical Specifications for NFC, IRE and UCIL facilities. The objective was to develop a more precise basis of regulation for these facilities and their activities. It was a difficult process to shape up the technical specifications for such facilities. The plant personnel, who were to prepare the specifications, were not familiar with the concept of technical specifications as viewed in the context of reactors or other similar facilities. After considerable efforts by the working groups and the unit safety committees, SARCOP could issue a very compact and concise document containing only requirements concerning radiological, industrial and environmental safety. These technical specifications now form a formal basis of safety requirements and regulatory reporting for these facilities.

Narora Fire Incident

March 31, 1993 saw an event, which caused a significant change in the manner in which issues of potential for common cause failures and quality assurance were approached by AERB and also significantly altered the style of regulatory functioning of AERB. The event involved a major fire in the turbine building of NAPS unit-1, that resulted in a total loss of power to the unit for over 17 hours.

The incident was initiated by failure of two turbine blades in the last stage of the low pressure turbine, which resulted in severe imbalance in the turbo-generator leading to rupturing of hydrogen seals and lube oil lines, leading to fire. The fire spread to several cable trays, relay panels, etc., in a short duration. The operating crew responded by tripping the reactor by manual actuation of primary shutdown system within a minute of the turbine failure and also initiated fast cool down of the reactor. The fire had spread through the generator bus duct in the Turbine Building (TB) and through cables into the Control Equipment Room (CER), where fire barriers had given way. There was heavy ingress of smoke into the control room, mainly through the intake of ventilation system, forcing the operators to vacate the control room. Loss of indications due to burning of control cables rendered the supplementary control room also unusable. There was widespread damage to the power cables as well as the control cables. Hence, even though the power sources were available, neither the power supply from the grid nor from the diesel generators or from the batteries was available to the essential equipment. This resulted in a complete loss of power supply in the Unit after about 7 minutes of the incident that continued for a period of 17 hours. During this long blackout, operators injected firewater into the secondary side of Steam Generators, with the objective of removal of decay heat from the core through thermo-siphoning in the primary side.

There was no radiological impact of the incident. The major fire was put out in about 90 minutes. The event was rated in the INES scale at level-3, mainly on account of the degradation of defence-in-depth of engineered safety features during the incident. This was one of the most serious events that the Indian nuclear industry came across till date. Soon after the event, AERB constituted an investigation committee under S.K. Mehta, then Director Reactor Group, BARC, who had also been the Chairman of NDSC earlier. Three months later the investigation committee submitted its findings and recommendations, which set in motion a spate of follow up action across the NPPs, both under construction as well as in operation.

The most prompt one was to take up immediate inspection of turbines in all the operating NPPs, which was followed by modifications in the LP turbine blade root design. The inspections indeed revealed presence of cracks in the blade roots in MAPS units. AERB had also insisted that all NPPs must establish and comply with limits on permissible vibration levels, operable grid frequency range and generator hydrogen make up rate. It also insisted the NPPs to follow a regime of pre-service inspection and in-service inspections for the turbines after specified service periods.

Based on the recommendations of the investigation committee, a large number of modifications and improvements were mandated in all NPPs, addressing various aspects covering design, operation and administrative and surveillance practices. One study was with regard to the susceptibility of the existing design and layout of NAPS, to common cause failures (CCF), mainly due to fire as an initiating event. Consideration was given to formulate preventive measures for avoiding CCFs, as well as to the need for additional mitigating measures for assured core cooling under station blackout situations. The review, initially carried out for NAPS, was subsequently extended to cover all other operating stations and the ones, which were under construction at that time (RAPP-3&4 and Kaiga-1&2). There was a close follow up from SARCOP and OPSD, for timely implementation of the recommendations at all stations. This included a number of inspections of the plants by OPSD and AERB inspectors for verification of the 'on ground' status. The actions taken at various plants pursuant to the NAPS-1 fire incident resulted in definite improvements in the areas of prevention and mitigation of fires, plant survivability against common cause failures and emergency operating procedures to deal with station black out situations.

NAPS Unit-2, which was under annual shutdown at the time of fire incident, was not affected by the fire incident. Restart of NAPS-2 was however permitted by AERB, only after implementation of the recommended modifications. The unit was restarted in November 1993.

The fire in Unit-1 had caused serious damage to the turbo generators, the cables and nearby equipment. There was significant damage to the civil structures in the turbine building including the TG foundations, requiring very focused efforts with respect to damage assessment, development of restoration methodology and its implementation and confirmatory tests to assess fitness of the structures. Recognizing the special attention required in this regard, AERB constituted a committee of experts in Civil Engineering to carry out review and advise AERB on various aspects related to the rehabilitation. This committee went on to become the Civil Engineering Safety Committee for Operating Plants (CESCOP), a standing committee to look after the civil and structural engineering issues of operating plants.

Restart of NAPS-1 was permitted only in December 1994, after restoration of the plant systems / structures and implementation of all the outstanding recommendations of NDSC and SARCOP.

Prior to the NAPS-1 fire incident, there was no systematic programme for conducting regulatory inspection of facilities by AERB. The inspections were essentially a sort of reactive, need-based affair, mostly following some events occurring in the plants or projects. Investigations into the NAPS fire indicated that certain recommendations of NDSC made during the design reviews, particularly with respect to cable routing, were not fully implemented at NAPS. This observation, led AERB to take steps to strengthen the quality assurance organizations in the NPPs and to establish a special group in AERB, the Directorate of Regulatory Inspection and Enforcement (DRI&E), to carry out regulatory inspection and audit of the NPPs and other facilities on a regular and periodic manner.

SARRA: A paradigm shift towards Periodic Safety Reviews

An important development that took place during this period was the introduction of SARRA reviews for the operating NPPs, which could be termed as a step towards the periodic safety reviews. The operational safety reviews thus far consisted of the regular reviews, which focused mainly on the issues of compliance to technical specifications, operational events, and radiological and industrial safety performance, emergency preparedness, operational experience feed back, etc., and the special reviews undertaken following certain events / developments (some examples of the special reviews were described earlier). An elaborate multi-tiered system of safety committees was in place for conducting these routine and special reviews.

Multi-tier review mechanism

The system for review of operational safety put in place consisted of a hierarchy of Safety Committees, starting right from the plant level, at corporate level and at the level of the regulatory body. At the bottom of this hierarchy are the Station Operation Review Committee (SORC) / Plant Operation Review Committee (PORC) or simply the Plant Safety Committees, with membership including the plant management and O&M personnel, which would review the issues of safety concerning day-to-day operation of the plants. At the next level are the unit safety committees (corporate level), which oversees a group of plants of similar attributes, with membership from the peer groups viz., the technical support organization, AERB, the designers and representation from the plants concerned. Above these committees is the Safety Review Committee for Operating Plants (SARCOP), the apex committee for safety review and enforcement for all the facilities. The system works on the principle of 'management by exception'; wherein the issues of greater significance are reviewed at the higher-level committees. The committees remain accountable to AERB, in all their reviews. These committees also receive inputs from a number of expert groups / standing committees on specific technical issues.

This unique concept, stemmed from the philosophy that self-regulation is the best form of regulation and signified a high degree of safety culture, right across all the organizations involved. The underlying logic for this system comes from the fact that the persons nearest to the problem area are best equipped to identify, assess and seek solutions; and given the necessary support, they are best equipped to resolve the problem. The problems identified, the assessments made and the solutions proposed are all subjected to peer review in all the Safety Committees. The decisions of these committees are accepted by OPSD and AERB, after ensuring that, they are in line with the safety goals, principles and requirements laid down by AERB and the mutually agreed acceptance criteria. The primary responsibility for safety rests with the plant management but it is accountable to the safety committees and AERB.

Introduction of SARRA

Internationally there were concerns on the safety of the existing

NPPs, mainly on account of ageing issues and view of the evolving safety standards and concerns, in the early nineties. IAEA had prepared a document on 'Common Basis for Judging the Safety of Nuclear Power Plants built to Earlier Standards' and IAEA Safety Guide on Periodic Safety Review of Operational Nuclear Power Plants. With these developments in the background, in 1993, AERB decided to establish a system of 'Authorization for Operation of NPPs'. It was envisaged that the authorization for operation should have validity of a maximum of five years, beyond which the NPP would have to carry out a self-assessment according to the laid down procedure, prepare a Safety Assessment Report for Renewal of Authorization (SARRA) and submit it to the AERB for review. Detailed guidelines were given by AERB, bringing out the objectives and guidance for conducting the self-assessment and preparation of SARRA. The reviews were to cover performance of the plant and operational problems, events, in-service inspections, radiological safety including exposures and releases, environmental impact, reliability of plant systems, plant modifications, status of implementation of regulatory recommendations, status of documentation, generic safety issues and public concerns.

SARRA of Older Plants

The first round of SARRA review was conducted for the older NPPs, TAPS, RAPS and MAPS in 1993. For NAPS, it was done in 1996. The unit safety committees reviewed the SARRA and the issues identified for resolution and remedial actions. When the SARRA for the older plants was taken up, it was realized that guidelines had not provided for any systematic approach for addressing issues related to ageing and shortcomings with respect to 'current safety practices'. For TAPS, RAPS and MAPS, there were issues like absence of high pressure emergency coolant injection systems, safety related systems being shared between units, inerting of primary containment of TAPS, issues related to life management of coolant channels, problems of embrittlement of end shields, etc. Almost all of these issues were already known and there were recommendations made in the past, from SRC and SARCOP and also by the TMI and Chernobyl Taskforces. As part of the SARRA review, SARCOP brought up all such issues to the consideration of the Board of AERB.

The Safety Issues

Pending resolution of the issues brought up during SARRA, AERB did not take any decision regarding renewal of authorization. AERB however was getting concerned about such issues remaining unaddressed and the trend of certain important recommendations made by SRC and SARCOP pertaining to many of the plants, not only NPPs, remaining pending for a very long time. In this backdrop, AERB prepared a compilation of the important safety issues remaining unresolved in the DAE installations, in 1995, with the objective of bringing the status of the issues to the notice of the Atomic Energy Commission. The compilation of 135 issues applicable to a range of installations came to be popularly referred in the media as the "AERB Safety Issues". Following this, a number of Taskforces were formed in all the facilities to devise and implement action plans for resolution of the issues which were classified into four categories.

Category-1: Hardware Related Issues requiring replacement of defective components.

Category 2: Ageing related issues needing elaborate studies to assess the healthiness of various components as well as possible replacement of components which have been showing signs of deterioration.

Category-3: Issues involving analytical studies or computer based calculations on certain systems to assure that the earlier designs are safe.

Category-4: Upgradation Related Issues- Plants that have been built to earlier safety standards require an upgradation according to the current safety standards and this may involve assessment and modification.

With substantial efforts put in by the concerned facilities, these safety issues could be satisfactorily resolved in the next few years.

SARRA of NAPS

The SARRA of NAPS taken up in 1996 could be completed without much difficulty, as it was a relatively new plant, devoid of any issues of ageing and/or changing standards. The issues were mainly of management operational problems. Based on SARRA, its authorization for operation was renewed for five years.

Based on the experience of SARRA, AERB initiated preparation of two new safety guides on (a) Renewal of Authorization for Operation of NPPs (AERB/SG-O-12), which had given the requirement of an elaborate Periodic Safety Review (PSR), as prerequisite for renewal of Authorization and (b) Life Cycle Management of NPPs (AERB/SG-O-14).

Incidents: 1993-1998

The period between 1993-1998 saw certain incidents at the facilities other than NPPs and some enforcement actions being taken by SARCOP. The major ones pertain to: (a) Leakage of radioactive effluent containing Caesium-137 from the regenerant concentration tank (TK-9) of Waste Immobilisation Plant (WIP), Tarapur, in May 1995, (b) Fatal accidents of workers at the IREL's sand mining facilities at Manavalakurichi, Chavara and OSCOM, (c) Failure of the Zirconium Reduction Retort at the Zirconium Sponge Plant, NFC, (d) Fire incident in the ventilation duct of Zirconium Fabrication Plant, NFC, (e) Fuel handling incident of April 12,1994, at the CIRUS research reactor in BARC, (f) Incident of an irradiated fuel getting stuck at the dissolver port in Plutonium Plant, BARC, on March 18,1994, (g) Fire incidents at HWP, Baroda on June 22, 1994 and Heavy Water Plant (Tuticorin) on February 14, 1995, (h) Incidents of leakage of Hydrogen Sulphide gas in September 1996, at HWP (Kota), (i) Fire incident on March 14, 1998 at HWP Kota, involving burning of nearly 800 drums of sour oil stored at the site; and (j) problem of build up of tritium activity in Moticher Pond at KAPS site.

Failure of Zirconium Reduction Retort, NFC

SARCOP suspended operations of all the retorts at Zirconium Sponge Plant of Nuclear Fuel Complex because of an incident in which the top cylindrical body of a retort got separated from the bottom dished end and fell down. The failure was due to the poor quality of fabrication; the circumferential weld joint of the retort cylindrical body to the dished end had lack of fusion at some places, underwent sensitization and intra granular stress corrosion cracking. It appeared that radiography of the weld joint was not carried out. SARCOP permitted NFC to resume operation of ZSP using retort No.12Q with the stipulation that the retort shall be examined after 3 reduction runs by radiography, ultrasonic testing and in-situ metallography to assess any deterioration and further operating life. Clearance for further operation was based on the review of the results of these examinations.

Hydrogen Sulphide Leak: HWP (Kota)

At the HWP, Kota, three incidents occurred in quick succession: overflow of solar evaporation tank containing sodium sulphate, leakage of hydrogen sulphide gas and tube leak of a heat exchanger which resulted in hydrogen sulphide concentration in the nearby equipment area upto 50 ppm. While reviewing, SARCOP observed that these incidents have originated from procedural deficiencies, insufficient investigations, insufficient analysis of the root cause, inadequacies in surveillance programme and training as reflected by poor operator response in mitigating the consequences of the incidents. Taking serious view of the overall situation, SARCOP directed on October 16, 1996 that the plant shall be shutdown and an action plan drawn up urgently and implemented to rectify the deficiencies; HWP (Kota) would be allowed to restart only after a review of the actions carried out and assurance for safe operation of the plant is obtained. The plant remained shut down on account of this directive till clearance was given on December 12, 1996, after satisfactory implementation of the corrective measures.

The Last Decade: Challenging Times

The period since 1998 had been very important in the history of regulation of operating plants in India. There were many important initiatives and developments during this decade. Four new NPP units entered the fold of operating NPPs under safety review coverage of SARCOP and OPSD, namely Kaiga Generating Station (KGS)-1&2 and RAPS-3&4, between 1999 and 2000. This was followed by the TAPS-3&4, the 540 MWe PHWRs, in 2006. There were a number of NPPs of older design, which were to be dealt with, particularly the NPPs at TAPS, RAPS and MAPS. These plants required careful reviews and assessments from the considerations of ageing and issues of life extension and long term operation.

Following S. Vasant Kumar, in October 1998 G.R. Srinivasan became the Chairman of SARCOP and the Vice-Chairman of AERB. He continued to serve in these capacities till his superannuation in December 2002. In April 2000, S.K. Chande replaced Naresh Kumar Jhamb, as the Member Secretary of SARCOP. In January 2003, S.K. Sharma took over the position of Chairman SARCOP and Vice Chairman AERB. He continued in these capacities till July 2004. He was followed by S.K. Chande, the present Chairman of SARCOP and Vice-Chairman AERB. Along with this R. Venkataraman became the Member Secretary of SARCOP.

In 2000, the Department of Atomic Energy had effected a reorganization, in which the safety review and regulatory responsibilities concerning the BARC facilities, which were involved in the strategic activities, were transferred to an internal safety review structure within BARC. With the internal reorganization of AERB happened in the same year, the responsibility for all aspects of safety surveillance, including regulatory inspections, with respect to NPPs and IGCAR facilities being given to OPSD and the same for Industrial and Nuclear Fuel Cycle Facilities being given to the Industrial Plants Safety Division (IPSD).

En-masse Coolant Channel Replacement and Safety Upgradation of RAPS-2

Between 1995 and 1998, RAPS Unit-2 underwent the en-masse coolant channel replacement (EMCCR), wherein the old Zircloy-2 pressure tubes were replaced with pressure tubes of Zirc-2.5% Niobium material, with four tight fit garter springs. The EMCCR was a major activity, involving cutting, removal and disposal of highly active, irradiated pressure tubes from the reactor core and re-installation and qualification of new pressure tubes, akin to a part decommissioning and part construction operation, worse being done with significant background radiation levels, was being undertaken for the first time in India. The job was expected to last for more than three years. The activity required development of procedures, tools, waste management methods and facilities and elaborate acceptance criteria. The entire job of EMCCR was carried out under close regulatory control and supervision of the RAPS-MAPS Safety Committee and SARCOP.

A dedicated Review Group was constituted by SARCOP for detailed review of all aspects related to the EMCCR campaign. The regulatory aspects included (a) identification of clearance stages for the activity, (b) review and qualification of various tools, procedures and personnel, (c) inspection, health assessment and qualification of the components that will be retained for further operation, (c) issues related to handling and disposal of the radioactive components removed from the reactor, (d) collective dose budget and performance, (e) aspects related to preservation of other plant systems during the extended outage period, (f) design safety review of the components being replaced.

SARCOP had asked NPCIL and RAPS to implement the safety related upgradations and health assessment related activities, identified / recommended as part of the safety reviews carried out in the past, during the long outage of EMCCR. This subsequently became the norm for all the plants going for EMCCR. In RAPS-2, a number of upgradations and inspections were carried out during the EMCCR outage. The important ones were,

- Incorporation of high-pressure emergency injection system to ECCS
- Provision of Supplementary Control Room
- Provision of additional Diesel Generator for catering to essential safety related loads in case of floods
- Segregation of Power and Control cables
- Inspection of elbows in PHT feeders and repair of feeders having reduced thickness margins
- Inspection and assessment of health of Steam Generator
- Provision of dedicated instrument air for essential loads in case of SBO and provision to isolate air supply to non-essential loads inside Reactor Building, in case of LOCA, to avoid re-pressurisation of RB
- Provision of additional relief valve for Bleed Condenser.

The regulatory reviews and clearances for recommissioning and restart of the unit after the EMCCR and upgradations were done in a manner, which was very similar to the processing of regulatory clearances for a new reactor. The EMCCR and upgradation jobs of RAPS Unit-2 were completed in April 1998. On May 5, 1998, when the commissioning activities were in progress, one of the moderator heat exchanger of the unit developed a tube leak, resulting in release of nearly five tons of moderator heavy water containing about 2600 TBq of tritium activity to Rana Pratap Sagar Lake. When the tube failure took place, as the condenser cooling water pumps were not in operation, there was no dilution of the released activity, resulting in pockets of excessive tritium activity in the water body. Though the activity released to the environment exceeded the technical specification limit prescribed for RAPS, the total radiation dose to the members of public due to this release was estimated to be about only 2% of the limit prescribed for the member of public. Following the event, SARCOP / AERB held up restart of the unit for nearly a month, pending investigations of the cause of the tube failure, detailed inspections, restoration and re-qualification of the heat exchanger.

As a result of this incident, SARCOP started enforcing measures such as (a) augmented in-service inspection of the heavy water heat exchangers at RAPS (b) early replacement of the defective heat exchangers and (c) sampling and analysis of the process water at increased frequencies.

Dealing with the Y2K Problem

At the turn of the century, “Y2K fever” appeared globally and nuclear industry was no exception. A small mistake of an earlier era practice of using only two digits to represent the year 19XX, carried forward by the computer programmers, was threatening to pose a serious problem. The millennium computer bug held the potential to disrupt the operations of infrastructure and public service systems wherever embedded computer systems were used which might calculate the change of date as 1900 instead of 2000, on transition into the 21st century. IAEA like many other international bodies made concerted efforts to raise Governmental and public awareness about Y2K issues and to exchange more and more information and experience, to head off the problems and to help set up contingency plans. Its public information system directory included Agency’s Action Plan, a technical guidance document on nuclear safety for achieving Y2K readiness and technical documents related to nuclear and radiation facilities.

Towards the end of the year 1998, SARCOP initiated a programme for dealing with the issues of Y2K in Indian NPPs, Research Reactors and Heavy Water Plants. The plan involved compilation of inventory of Computer Based Systems, their safety classification and Y2K readiness status, assessment, remediation and contingency planning, in line with the IAEA guidance on Y2K compliance. These activities were undertaken within the close coordination and supervision of a dedicated Y2K Committee constituted by SARCOP. The simplistic approach for dealing with the apparently complex issue of Y2K in the context of nuclear and radiation facilities was to treat it as a potential common cause failure which could affect the computer based plant systems.

AERB also established a nodal contact point for monitoring the status at all plants and facilities and to deal with any developing situation, at its Headquarters in Niyamak Bhavan, on the night of Y2K rollover. All members of AERB Y2K committee and experts from BARC, NPCIL and HWB were present at nodal contact point. The control room at nodal contact point was activated from 2000 hrs on 31st December 1999 to 0300 hrs on 1st January 2000 and the Y2K rollover status of all the plants were closely monitored. The monitoring involved predefined checks on the relevant systems at all plants, before and after the rollover. Contrary to the fears, the Y2K rollover occurred smoothly in all the DAE nuclear plants and Facilities without any event. The nodal contact point also functioned as a point for exchanging information on status of operating NPPs with international counterparts including the CANDU regulators and the International Y2K Early Warning System (YEWS) of USNRC. The AERB nodal point received advance information on Y2K transition in Eastern Countries like Korea and Japan, where the transition to the new millennium occurred several hours earlier. After successful Y2K rollover in India, an 'all normal' message was sent to the YEWS and CANDU regulators, through e-mail.

The Y2K rollover was smooth but it raised many a technology management issues, pot holes and challenges to uncover and resolve, in dealing with this black box technology and role of the regulatory bodies, to contain and control the cyber space infrastructure problems. It raised issues of bugs hidden in the embedded systems and the need for thorough validation and verification of software based systems. It also gave a feel of the complex problems the high technology systems, wherein the operating staff may feel helpless in dealing with unforeseen situations, due to lack of full understanding of the underlying technology.

Comprehensive Safety Review of TAPS-1&2 for Long Term Operation

As said earlier, the first round of SARRA reviews carried out for TAPS-1&2 reactors raised many issues. In the year 2000, after completing more than 32 years of operation, SARCOP and AERB directed TAPS to undertake a comprehensive assessment and review of safety for continued long-term operation of the units taking account of the actual condition of the plant vis-à-vis prevailing safety requirements. The review was required to address the aspects such as the design basis, safety analysis, operating experience and ageing management and residual life assessment. Subsequently AERB asked NPCIL to carry out a level-I Probabilistic Safety Assessment (PSA) and seismic re-evaluation also, as part of the comprehensive review.

The reviews were done based on the guidelines/approach as outlined in the AERB Safety Guide on Renewal of Authorization for operation of nuclear power plants (AERB/SG/O-12), which was then under draft stage. In addition, guidance from the NPC Headquarter instruction on 'Ageing Management of NPP components, systems and structures important to safety' and the IAEA INSAG-8 on 'Common Basis for Judging Safety of NPPs Built to Earlier Standards' and the USNRC standard review plan for review of safety analysis reports for NPPs (NUREG-800) were also utilized. A large number of reports were prepared based on these reviews, which were subsequently reviewed by TAPS Safety Committee and SARCOP. Some of the salient findings of the reviews are as follows.

Review of design basis and safety analysis

For review of design basis, each system was reviewed against the applicable general design criteria specified by US NRC. The review also covered aspects such as conformance with single failure criterion/ redundancy, defence-in-depth, physical and functional separation of components and common cause failure vulnerabilities. These assessments considered the effect of non-conformances on safety function capability, frequency of initiating events and the associated potential consequences. Insights from the results of a Level-1 PSA were also used for these assessments.

The safety analyses were redone using current analytical methods and state of art analytical tools, for enveloping cases of postulated initiating events (PIE). The safety report was updated to include these fresh analyses and the design modifications/ back fits. The revised analysis showed that the safety criteria were met with good margin for situations within the design basis. This scenario did not pose any potential threat to the containment integrity, as the hydrogen generation would be insignificant. The safety analysis also showed that inerting of containment might not be necessary for Design Basis Accidents (DBA).

The modern day safety requirements for NPPs call for consideration of severe accidents. For addressing this aspect for TAPS, a scoping analysis was carried out with the objective of identifying the scenarios requiring detailed realistic assessments, experimental work and development of severe accident management strategies. Based on this scoping analysis, further work in this direction is presently in progress.

Ageing management and operational performance

As part of this review, an exhaustive ageing assessment and management programme was worked out for the system, structure and components (SSCs) of the units.

First order assessments based on the results from examination of the surveillance specimens indicated that the Reactor Pressure Vessel material had adequate fracture toughness to assure safety of the pressure vessel. To address the issue of health of uninspectable welds of the reactor vessel, programmes were initiated for conducting a detailed fatigue analysis of the reactor vessel and also development of techniques and tooling for facilitating remote inspection of some of the welds in the reactor vessel. The other non-replaceable components viz., the primary containment, reactor building, the suppression pools, common chamber, and other civil structures were accessible for inspection and were found in healthy state. Detailed programmes have been finalised for taking up periodic inspection and health monitoring of these and all the other important SSCs, as part of the ageing management programme.

Seismic re-evaluation

Seismic re-evaluation of structures, systems and components (SSC) of TAPS was carried out for the latest ground motion parameters derived for the TAPS site. Re-evaluation of safety systems and safety support systems was done using seismic margin assessment method considering the ductility and damping factors given in IAEA Safety Reports Series No. 28 on 'Seismic re-evaluation of existing nuclear power plants'.

Based on these reviews and assessments, which were completed in 2003, requirements for safety upgrades were identified. The important ones among them were

- Extensive modification in the emergency power supply system for the station that included three new diesel generators of higher capacity and unit-wise segregation of power supplies to obviate common cause failures
- Segregation of some other shared systems such as shutdown cooling system and fuel pool cooling system;
- Addition of an independent set of CRD (Control Rod Drive)

pumps to strengthen the emergency feed water supply to the reactor;

- Addition of a supplementary control room; and
- Extensive upgradation of fire protection system.

These upgradations were implemented in the station during a planned long shutdown of both units of TAPS-1&2, between October 2005 and February 2006. Based on the findings of the comprehensive review and the safety improvements achieved through the upgradations and ageing management actions, which had satisfactorily addressed the outstanding safety issues, AERB renewed the authorization for operation of TAPS units in February 2006.

En-masse Coolant Channel Replacement and Upgradations in MAPS Units

During the EMCCR work at MAPS-1&2, several important upgradation were undertaken to enhance the safety of the units. These included:

1. Retrofitting of high pressure injection in Emergency Core Cooling System
2. Incorporation of Supplementary Control Room
3. Incorporation of sensitive leak detection system for coolant channels
4. Up-gradation of fire/smoke detection system
5. Installation of fire barriers, fire walls/doors in critical areas
6. Segregation of power and control cables for safety related systems

Taking advantage of these long outages, MAPS had also taken steps to implement some modifications, with the objective of improving performance and availability of the Units. The important among these were:

a. Replacement of steam generators, in view of the tube leaks making a significant part of the heat exchanger section unavailable and discovery of age related degradation caused by under deposit pitting corrosion of the tubes.

b. Installation of Spargers for moderator inlet to the calandria, to restore the design intended moderator flow configuration.

Subsequent to these upgrades and after detailed assessment of margins and regulatory reviews, AERB permitted operation of MAPS units up to 100% FP.

NAPS Safety Upgradation

The NAPS unit-1 underwent EMCCR during the period November 2005 – December 2007. Here too there were many upgradations / modifications implemented during the outage, the important ones being:

1. Replacement of PHT feeders
2. Provision of venting of end shields to obviate degradation of shielding efficacy during operation.
3. Installation of back up dew point sensors in Annulus Gas Monitoring System (AGMS), to improve reliability of pressure tube leak detection system
4. Upgradation of fire detection and alarm system
5. Replacement of existing moderator pumps with canned rotor pumps
6. Replacement of motor-generator sets with solid-state inverters
7. Replacement of existing analog type process controllers with microprocessor based controllers
8. Replacement of existing liquid poison tanks of Secondary Shutdown System

Periodic Safety Review (PSR)

As mentioned earlier, following the experience of SARRA reviews, AERB initiated preparation of a Safety Guide on Renewal of

Authorization for Operation of NPPs (AERB/SG-12). The Safety Guide was published in the year 2000. In the year 2002, AERB had formally instituted a programme for renewal of authorization for operation of NPPs based on a detailed Periodic Safety Review (PSR), as per the requirements laid down in the Guide. The programme envisages conduct of PSRs for every NPP at a periodicity of once in ten years as of present. However, taking into account the legal considerations governing issue of authorizations, which stipulates a maximum validity period of five years for the authorizations, the programme provided for a limited scope review called Application for renewal of Authorization (ARA), for the renewal intervening the PSRs.

The requirements of PSR stipulated in the AERB Guide are much in line with the IAEA Safety Guide IAEA/SG/O-12 on Periodic Safety Review. The PSR envisages safety assessment, covering a number of safety factors, eleven of them, taking account of the aspects such as improvements in safety standards and operating practices, cumulative effects of plant ageing, modifications, feedback of operating experience and development in science and technology. As per the requirement of PSR, the utility is required to carry out a comprehensive review covering the identified safety factors. The purpose of the review by the utility is to identify strengths and shortcomings of the NPPs against the requirements of current standards. Modifications or upgrades required to compensate for safety significant shortcomings should also be proposed as part of review. The report on the PSR is subjected to regulatory review, in the multi-tier review process established in AERB, for satisfactory resolution of the shortcomings.

The ARA on the other hand requires only a limited scope review of certain important aspects of plant operation such as safety performance, operating experience feedback, in-service inspection and major modifications carried out during the reporting period. The intent of such a review is to detect and monitor the trends of early signs of degradations, if any.

As per this programme, the Periodic Safety reviews of NAPS, KAPS and MAPS units were carried out in the years 2003, 2004 and 2005-06 respectively. These PSRs demonstrated that the safety status of these plants is satisfactory and there were no major shortcomings with respect to the current safety requirements / practices which have significant safety implications. However, based on the issues arising out of these PSRs, many improvements were initiated. Important among these were:

- Revision and updating of Safety Analysis, using state of art analytical tools/methods, addressing the current plant configuration and current list of initiating events
- Development and implementation of systematic programmes for Ageing Management and maintenance of Equipment Qualification
- Development and Implementation of action plans for reduction of Collective Dose
- Revision of Technical Specifications based on the operating experience
- Optimization of In-service Inspection Programme
- Seismic Re-evaluation of old generation PHWRs (RAPS and MAPS)

Impact of Tokai-mura accident

On September 30, 1999, a criticality accident occurred in the nuclear processing facility at Tokai-mura, Japan, in which three workers received very high radiation doses, resulting in the death of one of them. The accident occurred when the workers added about 16 kg of enriched uranium containing 18.8% of uranium-235, in a single tank, instead of the maximum permitted quantity of 2.4 kg, in violation of the approved procedure. SARCOP reviewed this accident and its relevance in the Indian context, in particular to the plants engaged in fuel fabrication and spent fuel reprocessing. SARCOP noted that these plants in India are designed conservatively with adequate safety margins to ensure that criticality incidents do not occur during operation. They are operated by duly trained and authorized operators as per approved procedures. In addition, continuous monitoring by the Local Safety Committee and periodic inspections by AERB ensured safe operation of the plant. However, as a prudent measure, SARCOP directed these plants to carry out a formal review of the design, procedures, internal audit, documentation, training and administrative controls to ensure criticality safety of the plant.

Incidents: 1999-2007

This last decade saw many interesting developments, events, issues and enforcement actions. The important ones among these were the incident of radiation overexposure of a person at RAPP Cobalt Facility (RAPPCOF) on October 15, 1999, following which the facility underwent intense scrutiny and safety upgrades, Steam Generator tube leaks in NAPS and KAPS units, incident of partial flow blockage in one of the coolant channels in RAPS -3 in May 2002, The Bhuj earthquake of January 26, 2001, the impact of Tsunami on December 26, 2004 at MAPS, the reactor power oscillations and modifications in the reactor regulating system in TAPS-3&4, the incident of red-oil explosion at New Uranium Oxide Fuel Plant (NUOFP), NFC on November 17, 2002, incident of failure of ash pond and failure of coal transfer rope way at HWP- Manuguru, etc. All these events were closely monitored by AERB. Some of these events are listed below.

Over Exposures at RAPPCOF

On October 15, 1999 two employees received external gamma radiation dose of 438.8 mSv and 40.5 mSv respectively at RAPP Cobalt Facility (RAPPCOF) at Rawatbhata. These persons were involved in taking out a shielding flask from the hot cell wherein 63 kilocuries (2.33 PBq) of cobalt-60 source sub-assemblies were lying unshielded on the hot cell table. The operator had opened the shielding door of the hot cell without noticing the presence of unshielded sources on the cell table. The employees got exposed to radiation from the open source in a short span of time before they realized the presence of the unshielded source in the cell. A Special Committee constituted by AERB investigated the incident. The Investigation Report indicated gross deficiencies in hardware, safety interlocks and radiation monitoring equipment; lack of procedural and administrative controls, lack of health physics coverage, lack of adequate training of personnel and inadequate documentation. In the light of these findings, SARCOP directed that the operation of the facility should remain suspended. Resumption of operations at the facility was permitted only after incorporating a number of safety related modifications, retraining and re-authorization of all plant personnel and a thorough review of the facility for safe operation.

Red Oil Explosion at NFC

During the early hours of 17 November 2002, an explosion occurred in the evaporator section of the solvent extraction plant of New Uranium Oxide Fuel Plant (NUOFP), NFC. No persons were injured. A preliminary review of the incident was done by SARCOP and subsequently Chairman, AERB constituted an investigation committee under the Chairmanship of S.K. Ghosh, Head, Chemical Engineering Division, BARC. SARCOP directed that till the investigations were completed and corrective measures were taken, operations in the wet section of NUOFP should remain suspended.

As per the investigation committee's report, the carry over of organic solvent into the evaporator along with the use of steam higher than set pressure resulted in rise in the temperature of organic-nitrate complex above 130 deg. C, taking the reaction into a run away mode and thereby leading to red oil explosion. SARCOP reviewed the report and endorsed the recommendations made by the committee. Only after the inspection by a team constituted by SARCOP, the permission to restart the operation was granted. Presently, process modifications have been carried out to eliminate the chances of red oil explosion.

Failure of Ash Pond at HWP, Manuguru

On January 17, 2004, there was an incident of breach in the bund of ash pond number 1 at HWP, Manuguru, resulting in escape of fly ash slurry from the pond into the public domain. About 19.5 acres of cultivated land and 8.5 acres of barren land were affected. The slurry discharge was brought under control in two days. It was established that the failure of the bund was due to improper drainage provision of water from the ash pond. This deficiency led to accumulation of excess water in the pond and the resulting hydrostatic pressure initiated the failure. HWB undertook failure analysis of the ash pond dyke and proposed a methodology for repair of the breached portion of the dyke. The report on the analysis and proposals for repair of the breached portion were reviewed by CESCOP and SARCOP. Based on the review, SARCOP granted clearance to undertake the repair and asked HWP to undertake a study to establish stability of the existing ash pond bunds and implement a maintenance program for the ash pond bunds. The plant was also asked to study the liquefaction potential and slope stability under seismic loading. Consequently, the ash pond bunds were strengthened and a programme for periodic maintenance and surveillance of the bunds is being followed.

KAPS-1 Incident of Regulating System Failure

On March 10, 2004, there was an incident involving failure of reactor regulating system resulting in uncontrolled increase in reactor power in KAPS-1. Prior to the event, reactor was operating at 75% FP. During the event, the power supply to all the adjuster rods of the reactor failed while preventive maintenance was being carried out on power UPS-1. Consequently, the reactor power started increasing and the reactor tripped on ‘Steam Generator delta T high’. The incident did not cause any damage to the plant and there were no radiological consequence. The event was rated at level-2 as per INES. The initial investigations and analyses could not adequately explain the reasons for increase in the reactor power encountered during the incident. Noting this anomaly, AERB had asked the affected Unit to be maintained under safe shutdown state till the underlying phenomena that resulted in this event was fully investigated and understood. Subsequently a Committee constituted by SARCOP carried out investigations and analyses on the event, which revealed certain new phenomena, which were not realised earlier.

At the time of the incident, KAPS-1 was being operated at a reduced power of 75% FP, in a peaked flux configuration, instead of normally followed flattened flux configuration. This was adopted as a policy of NPCIL at that time, in all PHWRs to maximize the utilization of the available natural uranium fuel. Due to this, there has been significant increase in the average in-core burn up of fuel, which was at 4900 MWD/T as compared to the normal value of about 3000 MWD/T, under the design intended flattened flux configuration. Analysis carried out taking account of this and the latest detailed neutronic cross section libraries, as recommended by IAEA showed that the reactivity feedback coefficients existing at the given reactor configuration differed from the ones that were considered in the design. After accounting for this, the behaviour of the reactor during the event could be explained. The review of the incident and investigations in AERB had also brought out several other shortcomings, in the form of deficiencies in areas of human performance and configuration of power supplies to reactor regulating system.

A number of corrective measures were identified to address the deficiencies observed in this event and to improve the safety culture and operating practices in NPCIL and its stations. These involved modifications in hardware, procedures, training and management systems. The specific measures taken at KAPS and other reactors included;

- Formal and elaborate retraining and re-licensing of all the frontline operating staff and the station management personnel. The training covered the safety aspects related to operation of the reactor in the peaked flux configuration, the reactor regulating system and safety culture.

- Establishment of a computerized operating experience feedback sharing system.
- Modification in the automatic liquid poison addition system to prevent manual inhibition.
- Modification in the configuration of power supplies to reactor regulating system.

AERB had stipulated that the operations of both KAPS Units could be permitted only after all the identified short-term measures were completed. As directed by AERB, KAPS Units remained shutdown till June 2004, for implementation of the identified actions. Restart of the unit was permitted in the first week of June 2004, after ascertaining the satisfactory implementation of the identified measures. Implementation of the actions arising out of the event was taken up in other units also.

Effect of Tsunami on MAPS

The Tsunami waves hit the east coast of India on the morning of December 26, 2004 and had affected the operation of MAPS Units, located at Kalpakkam. Unit-2 was operating while Unit-1 was under long shutdown for enmasse coolant channel replacement and safety upgradations, since August 2003. The water level in the seawater pump house of the plant had risen causing tripping of Condenser Cooling Water (CCW) pumps. The reactor was brought to cold shutdown state by following the emergency operating procedure. The increase in water level in pump house during tsunami made all the seawater pumps located in this area unavailable. Further, cooling of the reactor of MAPS Unit-1 and different loads were achieved by using the firewater system.

The damage caused by the tsunami was limited only to the peripheral areas, such as damage to the cement-brick wall at the plant periphery on sea side and inundation of roads on the east side of turbine building.

After a detailed review of the impact of tsunami, AERB permitted to restart the operation of MAPS Unit-2 in January 1, 2005. The Tsunami has brought out some important issues, which need detailed review and follow up in the context of safety of NPPs in the event of natural calamities. The telecommunication links to MAPS and Kalpakkam site had suffered severe degradation as the telephone exchange of Kalpakkam was damaged due to Tsunami. In the light of this experience, NPCIL had been asked to augment the communication facilities at Kalpakkam site and examine the need for providing diverse and reliable communication channels at NPP sites.

Life management of PHT feeders

Based on the reports from Canadian reactors, on the problem of thinning of PHT feeder elbows in the later half of nineties, AERB had asked NPCIL to examine the status of PHT feeders in RAPS and MAPS reactors. The inspections done in RAPS-2 which was under EMCCR showed noticeable thinning in some of the feeder elbows. Following this, a detailed exercise of assessment of residual life and repair of some of the feeders was carried out prior to restart of RAPS-2 after EMCCR in 1998. Full-scale inspection and health assessment was carried out in MAPS Unit-2 during its EMCCR, in 2003.

In the subsequent years, pursuant to the PSRs of NAPS and KAPS, SARCOP / AERB recommended instituting a programme for augmented inspections, health assessment and life management of feeders, as part of the ISI programme. The subsequent inspections and assessments indicated that the rate of thinning in some of the feeders is higher than the initially anticipated rates. The reason for the thinning appears to be flow induced erosion-corrosion of the feeder pipe. After the problem has been highlighted, NPCIL had taken a policy decision changing the material of the feeders, for better resistance to Flow Assisted Corrosion (FAC), in all new reactors. Also it was decided to use elbows of higher thickness, so as to increase the margins against FAC. NPCIL had also decided to replace the feeders in the operating reactors, at the time of coolant channels replacement. In line with this, feeders have already been replaced in MAPS-1 and NAPS-1, during their EMCCRs. Feeder replacement is also planned for NAPS-2 and KAPS-1, which are presently undergoing EMCCR.

In RAPS-2, en-masse replacement of feeders was taken up as stipulated by SARCOP, in July 2007, after inspections and assessments indicated very low margins existing in some of the feeders.

Flow Assisted Corrosion in High Energy Piping

Following the failure of secondary feed water pipe to steam generator in KAPS-2 in February 2006, SARCOP asked NPCIL to institute a surveillance programme for monitoring the health of high-energy secondary cycle piping in all the operating reactors. Pursuant to this, a comprehensive programme was undertaken by NPCIL in all stations to monitor the vulnerable areas of high-energy piping. As per this, nearly 3000-4000 locations were identified in each NPP, where thickness gauging was undertaken, for establishing the baseline data. Programmes have also been established based on analysis of the baseline data in all plants, for future monitoring and/or replacements. Compliance to this programme at all operating NPPs is being closely followed up by OPSD.

Summing up, the safety review process of AERB had originated as part of the Nuclear Power Programme. Over the years it has been established into a matured, responsible and effective system. The regulatory system followed by AERB is unique in many respects. The safety review and regulatory mechanism as established today has the support of a large number of committees at the plant level, nearly 20 unit safety committees, more than five expert committees established as part of the multi-tiered system, under AERB and SARCOP. The presence of stakeholder representatives in the safety committees has helped in better understanding of the ground realities and obtaining realistic commitments from the utilities. The participation of the utility representatives in decision making has been helpful in avoiding the need for coercive enforcement actions on the part of the regulator. It is often seen that having understood the concerns of the regulators, the utility voluntarily accepts the decisions taken by the safety committees and more often than not comply with the decisions in a timely manner.

The safety surveillance provided by OPSD and IPSD through its regulatory inspections and reviews has proved effective. The regulatory supervision by these divisions also ensure that the decisions taken in the safety committees are in tune with the safety goals and principles enunciated in various AERB Codes / Guides and Standards. The framework involving the Safety Committees and these Divisions of AERB has helped in evolving a decision making system which is flexible enough to adjust to the specific situations, taking into account the merit of each case, without compromising on the safety considerations.

The regulatory framework has been functioning effectively as a means of experience feed back. The system of renewal of authorizations has been effective in addressing the issues of evolving safety practices.

The safety review set up has seen a number of organizational changes, new faces came and gone, seen many developments, challenges, but evolved itself to meet all of them in a satisfactory manner. But there have been those attributes; high level of safety culture and professionalism, which remained intact all along.

Major inputs by: *S.K. Chande, N.K. Jhamb, S. Hari Kumar, P.C. Basu and R. Bhattacharya*